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Original Article

Study on the relationship between the thickness of the anterior cruciate ligament, anthropometric data and anatomical measurements on the knee☆

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ABSTRACT

Objectives: To ascertain thickness measurements on the anterior cruciate ligament (ACL) in its middle third on magnetic resonance imaging (MRI) scans and to assess whether there is any association between variations in ligament thickness and patients' heights and ages, along with variations in the anatomical measurements on the knee.

Methods: MRI scans on 48 knees were evaluated. The anteroposterior size of the femoral condyles, interepicondylar distance, intercondylar distance and anteroposterior and mediolateral thicknesses of the ACL were measured. It was assessed whether there was any statistical relationship between ACL thickness and the patients' age, height or other measurements evaluated.

Results: The mean thickness of the middle third of the ACL was 4.5 mm in the sagittal plane and 4.3 mm in the frontal plane. The anteroposterior thickness of the ACL in its middle third had a positive relationship with the size of the lateral condyle. The mediolateral thickness of the ACL in its middle third had a positive relationship with the size of the lateral condyle and with the intercondylar distance in the axial plane. There was no relationship between the thickness of the ACL and the patients' age or height.

Conclusion: The thickness of the ACL presented positive associations with the size of the lateral femoral condyle and the intercondylar distance.

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Estudo da relação entre a espessura do ligamento cruzado anterior, os dados antropométricos e as medidas anatômicas do joelho

Palavras-chave:
Joelho
Ligamento cruzado anterior
Anatomia
Imagem por ressonância magnética

RESUMO

Objetivo: Obter as medidas da espessura do ligamento cruzado anterior (LCA) em seu terço médio em exames de ressonância magnética e avaliar se existe associação entre a variação da espessura do ligamento com a altura e a idade dos pacientes, bem como com as variações das medidas anatômicas do joelho.

Métodos: Foram avaliados os exames de ressonância magnética de 48 joelhos, aferidas as medidas do tamanho anteroposterior dos côndilos femorais, distância interepicondilar, distância intercondilar e as espessuras anteroposterior e mediolateral do LCA e avaliamos se existe relação estatística entre a espessura do LCA e a idade ou a altura dos pacientes e as demais medidas avaliadas.

Resultados: A média da espessura no terço médio do LCA foi de 4,5 mm no plano sagital e 4,3 mm no plano frontal. A espessura anteroposterior do LCA no seu terço médio tem relação positiva com o tamanho do côndilo lateral. A espessura mediolateral do LCA no seu terço médio tem relação positiva com o tamanho do côndilo lateral e com a distância intercondilar no plano axial. Não encontramos relação entre a espessura do LCA e a idade ou a altura dos pacientes.

Conclusão: A espessura do LCA apresenta uma associação positiva com o tamanho do côndilo femoral lateral e a distância intercondilar.

Introduction

Reconstruction of the anterior cruciate ligament (ACL) is one of the surgical procedures most frequently performed within orthopedists' clinical practice and its results are well established in the literature.[1–6] Lack of success in reconstructing the ligament is related to poor positioning of the tunnels, non-treatment of associate lesions and problems relating to fixation and incorporation of the graft, along with inappropriate rehabilitation protocols.[7]

Recently, Magnussen et al.[8] correlated the diameter of the graft used with failure of ACL reconstruction. According to these authors, grafts with diameters less than or equal to 8 mm had a higher repeated tear rate than did grafts with diameters greater than 8 mm. Thus, the authors suggested that reconstructions should be performed with grafts of minimum thickness 9 mm.

Despite the advantage relating to using grafts that are as thick as possible, complications in standardizing this characteristic may lead to a disproportionate increase in the ratio between content and containment structure in the knee. This may generate pain, limitation of the range of motion and increased risk of failure of the reconstruction.[7,9]

Investigation of parameters that enable individualized surgical planning may improve the efficacy of treatment and diminish the risk of intercurrences during the intraoperative period. Factors predicting the graft that should be used in reconstructing the ligament are among these parameters Evaluation of the morphology of the ACL and its relationship with the anthropometric data and with the other structures of the knee may provide guidance of greater precision and lower risk in choosing the thickness of the graft to be used in ligament reconstruction surgery.[10]

The aims of this study were to obtain thickness measurements from the middle third of the ACL, using magnetic resonance imaging (MRI) examinations, and to assess whether there was any association between the variation in ligament measurements and patients' height and age, and also in relation to variations in anatomical measurements on the knee.

Methods

This was a retrospective study that had been approved by the Research Ethics Committee of Santa Casa de São Paulo. Forty-eight MRI examinations on the knees of patients who were being followed up at the Knee Group outpatient clinic of Santa Casa de São Paulo were evaluated. There were 25 examinations on women and 23 on men, and they were performed between January and December 2013.

The ages and heights of the patients examined were recorded. For the height measurements, the patients stood against a stadiometer in an erect manner, with arms extended along the sides of the body and head raised, without wearing shoes. The patients' mean age was 44.3 years and their mean height was 1.70 m.

Patients with skeletal immaturity, previous surgery or degenerative alterations in the knees were excluded.

The images were obtained in the Imaging Diagnostics Service of Santa Casa de Misericórdia de São Paulo, using an MRI machine of 1.5 T (Intera, Philips), with a specific eight-channel coil. Proton density(PD) weighted sequences in three planes (sagittal, coronal and axial) were used, with and without fat

Fig. 1 – Anteroposterior size of the femoral condyles.

Fig. 3 – Intercondylar distance in the axial plane.

saturation, using the following parameter: TE 1642, TE 30; matrix 512 × 256; FOV 16 × 16; slice thickness 3.5 mm; and slice interval 0.3 mm. The image analysis and measurements on all the parameters needed, and their correlations, were performed on workstations using the Agfa PACS/RIS system. This was done by two radiologists who were specialists in radiology of the musculoskeletal system, who analyzed the images together, simultaneously.

The following measurements were obtained from the MRI:

- Anteroposterior size of the medial and lateral femoral condyles, obtained from the PD-weighted sequence in the sagittal plane (Fig. 1).
- Interepicondylar distance obtained from the PD-weighted sequence in the axial plane (Fig. 2).
- Intercondylar distance obtained from the PD-weighted sequence in the axial plane (Fig. 3).
- Anteroposterior thickness of the ACL obtained from the PD-weighted sequence in the sagittal plane, by means of linear measurement in its middle third, perpendicular to the long axis of the ligament fibers (Fig. 4).
- Mediolateral (transverse) thickness of the ACL obtained from the PD-weighted sequence in the axial plane, by means of transverse linear measurements in its middle third, taking the greatest diameter of the ligament fibers (Fig. 5).

The results were organized by means of tables and graphs, and were then subjected to statistical tests to analyze and validate the results from this study.

Fig. 2 – Interepicondylar distance in the axial plane.

Fig. 4 – Anteroposterior thickness of the ACL in the sagittal plane.

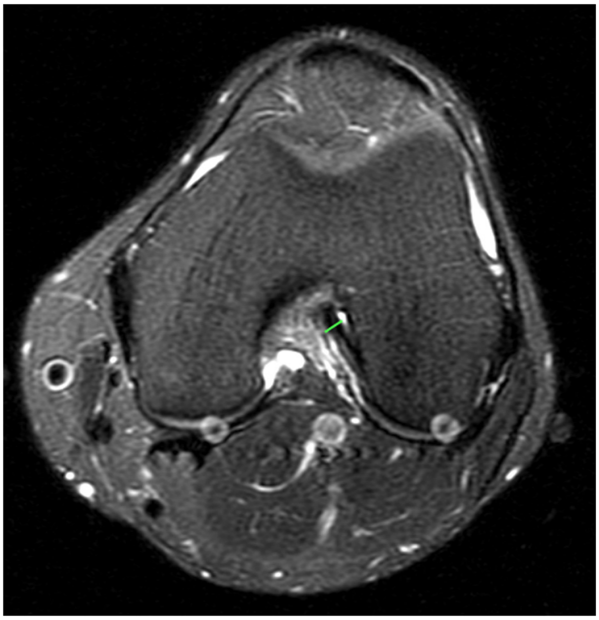

Fig. 5 – Mediolateral thickness of the ACL in the axial plane.

To perform the general descriptive analysis, the mean, standard deviation, minimum value, median and maximum value of each of the measurements were calculated.

To compare the thickness measurements from the middle third of the ACL with the other measurements of this study, Pearson's correlation coefficient was used. The significance level used was 5% (p-value $\leq$0.05).

The SPSS® software (Statistical Package for the Social Sciences, version 13.0; Chicago, IL, USA) was used for the statistical analysis.

Results

The mean thickness in the middle third of the ACL was 4.5 mm in the sagittal plane (range: 3.1–7.2 mm) and 4.3 mm in the frontal plane (range: 2.9–6.2 mm).

The mean size of the lateral femoral condyle was 62.2 mm (range: 48.1–74.7 mm), while the mean size of the medial femoral condyle was 55.7 mm (range: 43.2–67.4 mm). The mean interepicondylar distance was 77.8 mm (range: 61.8–91.7 mm). The mean intercondylar distance was 21.7 mm, ranging from 15.8 to 30 mm (Table 1).

It was seen that the anteroposterior thickness of the ACL in its middle third had a positive relationship with the size of the lateral condyle. We did not find any other statistically significant association involving the anteroposterior thickness of the ACL (Table 2).

It was observed that the mediolateral thickness of the ACL in its middle third had a positive relationship with the size of the lateral condyle and with the intercondylar distance in the axial plane. We did not find any other statistically significant association involving the mediolateral thickness of the ACL (Table 3).

We did not find any relationship between the thickness of the ACL and the patients' ages or heights. However, we observed a tendency toward a positive relationship between the anteroposterior thickness of the ACL and height ($p = 0.054$), but without statistical significance.

Discussion

Over recent decades, in attempts to diminish the failure rates from ligament reconstruction, different studies have evaluated aspects of the anatomy of the ACL[5,11] and the various surgical techniques used for ligament reconstruction.[2–7]

Magnussen et al.[8] demonstrated that there was an inversely proportional relationship between the thickness of the graft used in ligament reconstruction and the risk of repeated tearing. In this light, we studied the thickness of the ACL in its middle third, by means of MRI examinations, and we evaluated the existence of relationships between these measurements and the values for knee structures and the patients' ages and heights.

In our study, we found that the mean thickness of the middle third of the ACL was 4.3 mm in the frontal plane and 4.5 mm in the sagittal plane, using MRI. In the literature, we found conflicting results relating to the thickness of the middle third of the ACL. Kupczik et al.[12] found a mean thickness of 4.8 mm using MRI examinations, while Anderson et al.[13] found a mean frontal thickness of 4.75 mm in women and 5.6 mm in men, and a mean sagittal thickness of 7.6 mm in women and 8.7 mm in men. This difference shows the difficulty in obtaining ACL measurements from MRI examinations, due to the complex morphology of the ligament and the influence of the level of the slice studied on the measurement obtained.

Rezende et al.[9] demonstrated that a narrow intercondylar distance was a predisposing factor for ACL injury. We found a positive relationship between the mediolateral thickness of

Table 1 – General descriptive analysis for the numerical variables.

Variable	Mean	Median	Deviation	Minimum	Maximum
Age (years)	44.3	45.5	16.8	16.0	78.0
Height (meters)	1.7	1.7	0.1	1.5	1.9
Anteroposterior size of lateral condyle (mm)	62.2	61.2	5.4	48.1	74.7
Anteroposterior size of medial condyle (mm)	55.7	55.4	5.2	43.2	67.4
Axial interepicondylar distance (mm)	77.8	78.3	6.6	61.8	91.7
Axial intercondylar distance (mm)	21.7	21.7	3.0	15.8	30.0
Mediolateral ACL thickness (axial) (mm)	4.3	4.3	0.8	2.9	6.2
Anteroposterior ACL thickness (sagittal) (mm)	4.5	4.5	0.9	3.1	7.2

Table 2 – Relationship between anteroposterior ACL thickness (sagittal) and each of the variables.

Comparisons	Coefficient of comparison	p-Value
Anteroposterior ACL thickness (sagittal) versus height	0.280	0.054
Anteroposterior ACL thickness (sagittal) versus age	0.60	0.683
Anteroposterior ACL thickness (sagittal) versus anteroposterior size of medial condyle	0.147	0.320
Anteroposterior ACL thickness (sagittal) versus anteroposterior size of lateral condyle	0.398	0.005
Anteroposterior ACL thickness (sagittal) versus interepicondylar distance (axial)	0.265	0.069
Anteroposterior ACL thickness (sagittal) versus intercondylar distance (axial)	0.036	0.809

Table 3 – Relationship between mediolateral ACL thickness (axial) and each of the variables.

Comparisons	Coefficient of comparison	p-Value
Mediolateral ACL thickness (axial) versus height	0.113	0.444
Mediolateral ACL thickness (axial) versus age	0.085	0.565
Mediolateral ACL thickness (axial) versus anteroposterior size of medial condyle	0.040	0.786
Mediolateral ACL thickness (axial) versus anteroposterior size of lateral condyle	0.346	0.017
Mediolateral ACL thickness (axial) versus interepicondylar distance (axial)	0.265	0.069
Mediolateral ACL thickness (axial) versus intercondylar distance (axial)	0.299	0.039

the ACL in its middle third and the intercondylar distance in the axial plane. There are divergences in the literature regarding depictions of the relationship between ACL morphology and the morphology of the intercondylar region. Muneta et al.[14] studied 16 knees from cadavers and did not find any relationship between the width of the intercondylar fossa and the morphology of the ACL. Charlton et al.[15] and Dienst et al.[16] observed a positive relationship between the volume of the intercondylar fossa and the approximate volume of the ACL within the intercondylar fossa, through using MRI examinations on healthy knees. Anderson et al.[13] reported that the size of the ACL did not present a direct relationship with the size of the intercondylar fossa, while Stijak et al.,[17] in a study on cadavers, observed that the thickness of the ACL had a positive correlation with the intercondylar distance only among males.

A positive association was found between the thickness of the ACL in its middle third, both in the frontal and in the sagittal plane, and the size of the lateral femoral condyle. We did not find any studies in the literature evaluating these relationships, but it is plausible to expect that knees of greater diameter will have greater dimensions for all of their anatomical structures, and not just the ACL.

No statistically significant relationship was found between the thickness of the ACL and age. We also did not find any statistically significant relationship between the thickness of the ACL and the patients' heights, although there was a tendency toward a positive relationship between the anteroposterior thickness of the ACL and height, but with $p = 0.054$. Brown et al.[18] studied 414 knees by means of MRI examinations and found a positive correlation between the length of the ACL and the patients' heights. This association is especially important when the ACL reconstruction is done using a graft from the patellar tendon. Those authors did not evaluate any associations involving the thickness of the ACL. Chan et al.[19] evaluated the thickness of the flexor tendons (semitendinosus and gracilis) using MRI and through observation during the operation, with regard to whether there might be any association between these measurements and the patients' heights. They found a positive association between the patients' heights and the thickness of the flexor tendons only through the intraoperative data. No association was found between height and tendon thickness through MRI. This finding raises the question of whether the patients' heights have a positive relationship with the thickness of the ligament per se. In our investigation of the literature, we did not find any studies that had evaluated this association. Although our study did not find any association between ACL thickness and height, we found a positive tendency. A study with a larger sample would possible prove the existence of such an association.

The limitation of the present study was that the measurement of morphological structures by means of MRI presented a discrepancy in relation to measurements made on cadavers. However, it is shown in the literature that this difference in measurements does not interfere with the analysis and the conclusions reached from these data.[20] Another point was the difficulty in establishing a relationship between the findings of the study and the problems within clinical practice, such as what the relationship is between measurements obtained from the middle third of the ACL and the size of the graft used in reconstructing the ACL. This occurred because the measurements were made in two planes (axial and sagittal) but the ACL is a three-dimensional helicoid structure, which makes it difficult to establish an exact geometric relationship between these parameters.

Conclusion

The mean thickness of the ACL in its middle third was 4.5 mm in the anteroposterior plane and 4.3 mm in the mediolateral plane.

A positive association was found between the thickness of the middle third of the ACL in the sagittal plane and the size of the lateral femoral condyle, and also a positive association between the thickness of the middle third of the ACL in the frontal plane and the size of the lateral femoral condyle and intercondylar distance.

Conflicts of interest

The authors declare no conflicts of interest.

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